
TECHNICAL PAPER # 65

UNDERSTANDING INTEGRATED PEST MANAGEMENT

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Published By

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Understanding Integrated Pest Management

ISBN: 9-86619-304-9

PREFACE

This paper-is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of intrest to people in developing countries. The papers are intended to be used as guidelines to help people chooe technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Patrice Matthews handling typesetting and layout, and Margaret Crouch as project manager.

The author of this paper, David Pimentel is a professor of Entomology at Cornell University in Ithaca, New York. It was reviewed by H.C. Cox, a consultant in agriculture, Michael Dover, an environmental consultant, Jon Myer, an engineer at the Hughes Research Laboratories, Ron Stanley, who is employed by the Environment Protection Agency in agricultural development, and Allen Steinhauer, the Executive Director of Consortium for International Crop Protection.

VITA is a private, nonprofit organization that supports people working on technical problems in developing countries. VITA offers information and assistance aimed at helping individuals and groups to select and implement technologies appropriate to their situations. VITA maintains an international Inquiry Service, a specialized documentation center, and a computerized roster of volunteer technical consultants; manages long-term field proejcts; and published a variety of technical manuals and papers.

UNDERSTANDING INTEGRATED PEST MANAGEMENT

by VITA Volunteer David Pimentel

OVERVIEW

When the new synthetic pesticides were first used on world crops in 1945, some people believed that the `magic bullet' or ultimate specific weapon for pest control had been discovered. As a result, ecological studies of pests--their life histories and environment--declined and investigations of nonchemical control were drastically reduced. In the industrialized countries, pesticides were the main method of pest control for nearly three decades.

With pests destroying about one-third of all crops in the world and the significant damage occurring in developing countries [Reference 1), it is no wonder that many farmers felt desperate enough to consider that pesticides were the only solution. Certainly, for a short time, there was widespread hope that losses to pests could significantly be reduced by the use of pesticides.

In fact, heavy pesticide use did result in major reductions in the damages by some pests for short periods, but no overall reduction in losses from pests has occurred. For example, since 1945, U.S. crop losses to pathogens and weeds have fluctuated but have not declined.

Changes in Agriculture

Rather, surprisingly, U.S. crop losses due to insects have nearly doubled (from 7 percent to about 13 percent) [6]. This has occurred in spite of a more than 10-fold increase in the use of pesticides, including insecticides. Fortunately, in recent decades, the impact of this loss has been offset effectively by increased crop yields. The increase has resulted from planting higher-yielding varieties and using more fertilizers, other fossil-energy inputs, and irrigation. Similar changes in crop-growing practices occurred throughout the world.

The significant increase in insect damage to U.S. crops can be accounted for by some of the major changes in agricultural practice since the 1940s. These include the planting of crop varieties that are susceptible to insect pests; destruction by pesticides of such natural enemies of pests as beneficial insects and mites; and increased use of fertilizers. In the United States as elsewhere, all of these changes required additional pesticide treatments, for example in cotton, and led to the development of pests resistant to pesticides. Moreover, reducing crop rotation and crop diversity and increasing the use of single crop varieties (monoculture) resulted in the need for more insecticide use, for example in maize. Concurrently, the U.S. government reduced tolerance levels for insects and insect parts in marketed foods, and processors and retailers raised `cosmetic standards' for more perfect fruits and vegetables.

Farmers removed less crop debris from their fields and orchards, often to achieve the benefits of reduced water evaporation and soil erosion. However, the practice also often led to increased pest problems. For example, less attention is now given to the destruction of infected fruit and crop residues (e.g., apples). Reduced tillage, with more debris left on the land surface, has become common.

The culturing of such crops as potatoes and broccoli has been extended into new climatic regions and made them more susceptible to insect attack. In addition, the use of pesticides that alter the physiology of crop plants has made some crops (maize, for example) more susceptible to insect attack.

Costs of Pesticide Use

Pesticides have helped to control some posts. However, their heavy use has brought serious social consequences and extensive changes in the environment. Human poisonings by pesticides are the highest price paid for intensive pesticide use. Each year in the world, an estimated 500,000 humans are poisoned by pesticides, with 10,000 fatalities.

Another indirect cost of pesticides is the reduction in the numbers of natural enemies of pests. When this occurs, more pesticide must be used to control the resulting pest outbreaks. With cotton, for example, four to five additional sprays are applied to compensate for the destruction of natural enemies of the cotton bollworm and budworm. Annually, the cost of these added sprays needed to offset the loss of natural enemies on U.S. crops amounts to an estimated US $153 million.

High pesticide use often results in pests that develop resistance to the chemicals. To cope with this, growers apply higher doses, additional sprays, and more powerful pesticides. The estimated annual cost of coping with increased pest resistance to insecticides for U.S. crops is about $134 million and for the world, $600 million. Yet, increased pesticide use encourages further resistance and amplifies environmental problems associated with their use. Other harmful effects of pesticides include the destruction of honey bees, reduced pollination, fish kills, and the unintentional killing of crops (herbicides, etc.). Overall, the

environmental and social costs annually total at least $1 billion world wide.

Given this background to the problems associated with the `single factor' approach to pest control with pesticides, several scientists suggested the need for an approach that considered many environmental factors, even if their consideration led to controlling just one factor in the environment. Studies of apple-pest control in Canada in the early 1960s and of malaria-carrying mosquitoes in the Tennessee Valley (USA) in the 1930s were the forerunners of integrated pest management, confirming the need for an interdisciplinary systems approach to pest control. This was an approach that took into account the interactions among pest species and with plant hosts, as well as the life histories and environments of both. (Nonchemical controls had, of course, been used with and without chemicals for many years. Interest in integrated pest management (IPM) has grown and has now become the stated goal of most pest control operations in most countries.

This paper examines the complex nature of pest problems and evaluates both chemical and nonchemical controls. The objectives of IPM are assessed, together with its current accomplishments and its future as a pest-control strategy. Although the paper emphasizes agriculture, the concepts and strategies of IPM can also be applied to forestry, the management of range and pasture land, the control of insects that carry human and animal diseases, and the control of such urban pests as rats and cockroaches.

The agricultural uses of IPM vary greatly with local conditions.

In addition to the general concepts in this paper, specific information is available in most countries from international agricultural centers and government research stations.

STRATEGIES OF INTEGRATED PEST MANAGEMENT

Integrated pest management is a technology for controlling agricultural and other pests for the benefit of society as a whole. In agriculture, pest-control strategies must consider not only the pest in its total agricultural environment, but also the surrounding environment and society that agriculture serves.

In developing strategies for an IPM program, reliable information on the following is vital:

1. The ecological basis of the pest problem.

2. Factors in the agroecosystem that can be manipulated to make the overall environment unfavorable for weeds, insects, and plant pathogens while producing an optimal crop yield.

3. A target level for reducing the post population, below which the degree of damage is acceptable.

4. Pest and natural enemy population trends, based on careful monitoring, to determine if and when pesticide treatments are necessary.

5. An analysis of the benefits and risks of the proposed IPM

strategies for the farmer and society as a whole.

Knowledge of the ecological basis of the pest problem, discussed in depth later, suggests ways to alter the crop environment to reduce pest problems and losses. Some nonchemical environmental manipulations to control pests will also be discussed.

IPM is a first line of defense. Not all pest problems, however, can be solved by manipulating factors in the crop environment. Thus, the second line of defense is the use of pesticides. When a pesticide is needed, it should be used, but in such a way as to cause minimal damage to the natural enemies that also are important controls of the major and potential pests. This requires extensive knowledge of the ecology of the pest as well as that of beneficial natural enemy populations. With adequate information on beneficial and pest populations, a pest-control specialist can determine which pesticide to use and when to apply it for maximal effectiveness.

The decision of when a pesticide should be applied will also depend on the level of injury by the particular pest at which there is a significant economic loss. Determining `economic injury levels' requires detailed knowledge of the following:

1. Density of a pest.

2. Densities of its parasites and predators.

3. Temperature and moisture levels and their impact on the crop,

pest, and the pest's natural enemies.

4. Level of soil nutrients available to the crop.

5. The growth characteristics of the particular crop variety.

6. Crop(s) grown on the land the previous year.

Of course, using a combination of nonchemical controls plus keeping pesticide applications to a minimum has environmental and public health advantages while at the same time being important to the farmer. First of all, reducing pesticide use reduces crop production costs. Second, and equally important, using a combination of controls including pesticides reduces the chances of the pests being able to overcome all of the control technologies. This relates especially to overcoming the resistance to the pest that the host plant has (`host-plant resistance') or can develop As a result, the useful life of both nonchemical and pesticidal controls and their benefit to society could be extended. Another important reason for using several control methods is that the climatic and other environmental factors change and may render one or more control factors less effective than usual.

Although nonchemical controls offer fewer risks to the environment than do pesticides, they are not without risks. The final and perhaps the most important step in developing successful IPM strategies entails a careful benefit and risk analysis of the

technique, including measuring its environmental and social costs. This is essential if the control program is to provide maximum benefits to agriculture and society as a whole.

IPM is a highly complex technology, even if the complex ecology of pest groups in an agroecosystem is understood (see diagram in Figure 1). Furthermore, manipulating the numerous factors in an

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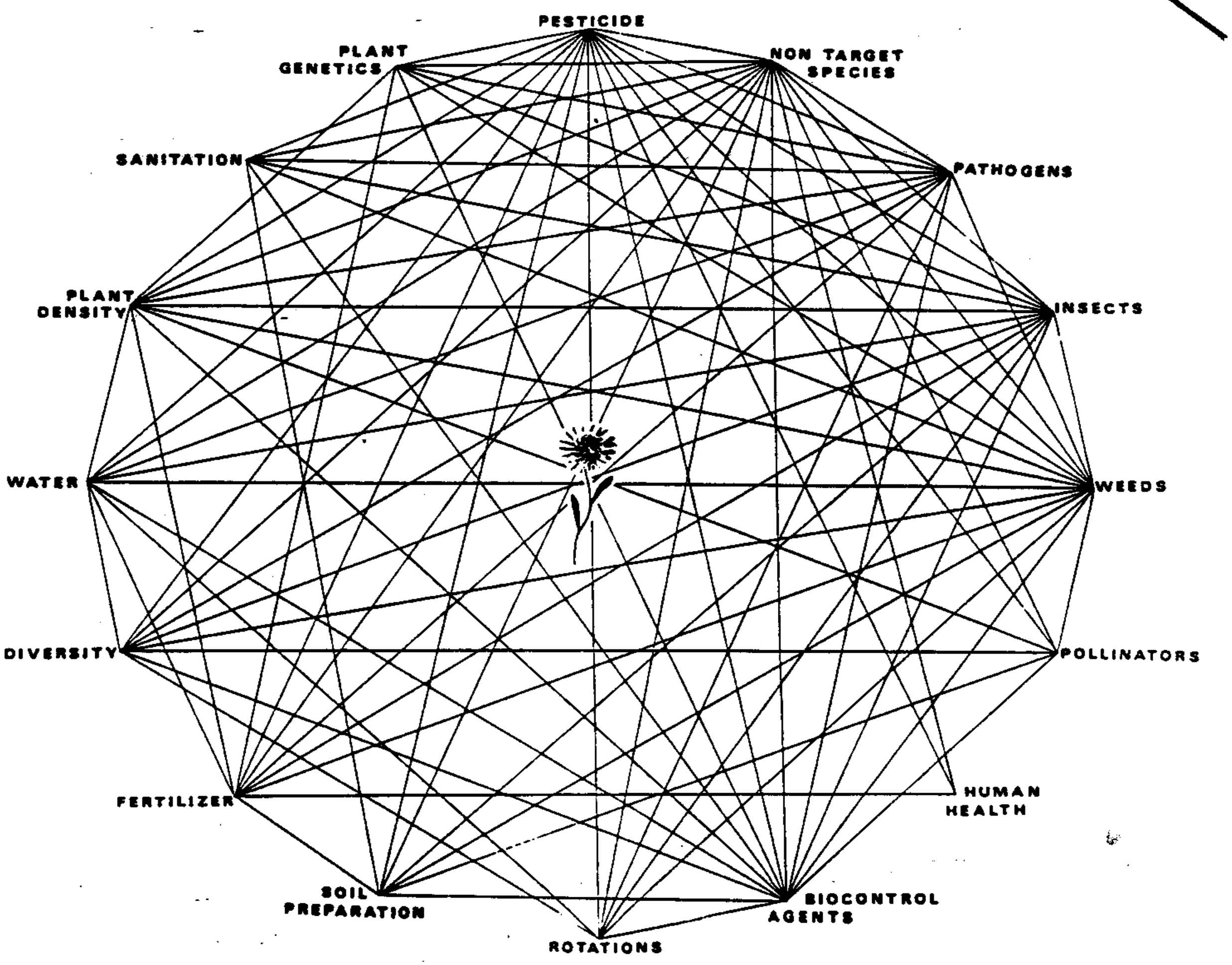

Figure 1

The interrelationships of the factors involved in the control of insect, pathogen (crop diseases), and weed pests associated with a particular crop plant.

agroecosystem to make the environment of a pest unfavorable while maintaining a favorable environment for the crop is a major challenge. Selecting' and balancing nonchemical controls and pesticides to use in combination is a difficult task. The process can be aided by carefully analyzing the benefits and risks of an IPM program, taking environmental and other biological factors into consideration as described above.

Although IPM has a complex basis, it sometimes uses only one control technique; for example, in some situations well designed and managed crop rotation can reduce the level of a pest population to tolerable levels, and keep it there, without the use of other types of control methods.

NONCHEMICAL PEST CONTROLS

IPM uses combinations of nonchemical pest controls including biological controls, host-plant resistance, cultural, and other techniques. The term "nonchemical control" refers to human activities that manipulate the pest's environment, its ecological relationships, or a combination of these [5, 6]. Again, it must be emphasized that there are no instant, magical control measures, whether they are pesticides or nonchemical controls. Pest populations must be managed in the context of the total agroecosystem (4).

Resistance of Host Plants

Many plants in nature have evolved to limit the feeding of pests on them. Through careful selection and breeding, genes can be incorporated into a cultivated plant that confer resistance to specific pests and thus provide effective control. For example, the Hessian fly, a serious pest of wheat, is effectively controlled on a large portion of U.S. wheat cropland because the wheat is bred for resistance to the fly.

Similarly, the spotted alfalfa aphid in controlled on most of the U.S. alfalfa crop by host-plant resistance. Resistance to the pea aphid has also been bred into some alfalfa varieties and is helping to control this pest.

To date, the most successful use of host-plant resistance has been in the control of plant pathogens. Breeding for disease resistance is a widely used control strategy, and now most major crop varieties have been developed to incorporate varying degrees of resistance to one or more important diseases. For some crops, like small grains, up to 98 percent of the world total is planted to resistant varieties.

In selecting and breeding plants for host-plant resistance to pests, the nutrients or the level of chemical toxicants in the new variety may be altered and the plant's resistance to pests enhanced thereby. For example, some standard maize varieties with high levels of carotene (vitamin A) have been found to be more resistant to maize leaf aphids than lines with lower levels of carotene. However, high levels of vitamin A can be harmful to animals and humans, and such changes need not be beneficial to humans and livestock using the maize.

In addition to variations in nutrient levels that often affect levels of pest populations, many plants produce chemical toxins that diminish or prevent pest attack. For example, the potato plant produces them in leaves, stems, and sometimes even in the tuber. At certain dosages these are toxic to some pests; unfortunately, for potatoes that have turned green from being left in sunlight, they can also poison humans.

Parasites and Predators for Biological Control

The deliberate use of predators and parasites, including microorganisms, to control several insect pests has proved to be highly successful. The first effort to employ predators and parasites for biological control occurred late in the 19th century when the Australian Vedalia beetle was brought to California to control the cottony-cushion scale on citrus [7). Since then, this technique has been used extensively on more than a million hectares of crops including citrus and olive [2]. Effective biological control in being achieved on other crops like apples, alfalfa, and maize [7]. Possibly the most successful biological control project to date is the importation from Argentina of a wasp that (dropped from aircraft in Africa) parasitizes the cassava mealybug. This project has reduced cassava losses from 80 percent to 40 percent of the crop; the crop losses since 1973 are estimated at $5.5 billion.

In addition to controlling insects, predators and parasites can control plant pathogens. Recent research at the USDA Beltsville laboratory has demonstrated that one species of fungus parasitizes a different one that causes 'leaf spot' in lettuce and more than 200 other food crops. Great potential exists for the expanded use of biological control measures against plant pathogens.

Insects and microorganisms are also used to control weeds [7]. One of the most successful examples of this was the introduction of two species of leaf-feeding beetles to control the Klamath weed pest in California. As a result, the weed has been controlled effectively on more than 1.5 million hectares of cropland, both in California and neighboring states.

Great care must be exercised in using plant-feeding insects and plant pathogens for weed control, because they may pose a threat to crop and natural plants in the total system. No major problems have resulted in modern times from the introduction of biological controls for weeds. Indeed, the existing levels of risk are very low because of the ways that research is conducted and its results made available to farmers.

Crop Rotation and Multiple Cropping

Rotation of crops is a most useful technique for controlling pest insects, diseases, and weeds. The adverse effect on pest outbreaks of continuous culture of the same crop on the same land has been discussed. Therefore, it is not unexpected to find that rotation of crops such as susceptible maize, in an appropriate sequence with other crops, results in effective control of the maize rootworm complex. Multiple cropping and intercropping can reduce pest populations and the damage they inflict.

Although many crop rotation programs help to control some pests, inappropriate rotation of crops may cause other problems. An example of this is planting potatoes after a crop of pasture grasses, which may result in serious wireworm problems. This emphasizes the need to take into account the total system when managing crope and pests.

Timing of Planting

Some pests can be controlled, or their injury reduced, by planting the crop when the pest is not present. In this way, the most susceptible stage of crop development does not coincide with the peak of the pest population. This strategy is used for controlling the Hossian fly: large areas of wheat are planted well after the Hessian fly has emerged and when a large percentage of the population has died for lack of suitable host plants. The technique has also proved to be effective in reducing the damage from root and crown rot in winter wheat and winter barley.

The prime risk is in exposing the newly planted crop to another pest that may emerge at the new planting time. Other risks of altered planting times include exposing the crop to drought if rainfall in less during the later cropping schedule, to frost if planted too early, or to immaturity at harvest if planted too late.

Genetic Methods

The technique of releasing insects that have been sterilized by gamma radiation or by chemical sterilants, to compete with other insects for mates, has been highly successful with the screw-worm fly. Release of sterile screwworm males destroyed the reproductive capacity of the screwworm fly population and eradicated the pest from the United States and parts of Mexico. In some parts of California, it has been successful against the Mediterranean fruit fly. Although the goal in these cases was eradication, the sterile-male technique is of potential value in IPM. But the technique is not successful against all kinds of insect pests, and some pest populations may become "resistant" to it. Other genetic technologies such as introducing lethal genes and male-producing genes also offer potential for insect-pest control.

There is a chance of releasing a new genotype that will present a greater risk than those already present. In addition, if some pests are not completely sterile when released, they may reproduce and contribute to the pest problem. The risks are acceptably small under today's conditions of agricultural research.

Water Management

The enhancement or curtailment of water supply to crops alters the ecosystem and in this way sometimes helps to control insect pests, plant diseases, and weeds. For instance, irrigation of alfalfa fields has been reported to encourage vigorous fungal attacks on the spotted alfalfa aphid and pea aphid populations.

Limiting the application of irrigation water to only the root area of a plant and avoiding wetting the leaves and fruit may reduce certain disease outbreaks in apple and citrus crops. The flooding of rice fields has been managed to suppress certain weed species [7].

Unsuitable water applications to crops can encourage plant pathogen outbreaks such an scab on apple trees and mildew on cucurbit crops.

Soil Management

Simple techniques such an tilling the soil often help to control certain pests. For example, U.S. wireworm populations, which have a two-year life cycle, can be reduced by plowing the fields during the summer. Mechanical injury, exposure to summer heat, bird predation, and low humidities probably account for most of the mortality in the wireworm populations.

Turning over the soil buries most plant pathogens present on the surface, thereby reducing the chance for future crop infections [3]. Worldwide, soil manipulation is the primary means of weed control. Young weeds are uprooted, buried, or disturbed, resulting in a high mortality in weed populations, especially when conditions are dry.

Tilling the soil destroys some pests effectively; however, at the same time, tillage exposes the soil to wind and water erosion. Soil erosion has become a major environmental problem in the world and primarily is due to use of the plow for weed control. The risks and benefits of this strategy must be evaluated. Minimum tillage offers a different set of benefits and risks.

Sanitation

For years, agriculturalists have known that field sanitation is an effective way to control insects, plant diseases, and weeds. Plowing-under crop residues has, for a long time, proved to be an effective technique for controlling various pests that otherwise might over winter for the next growing season. Many weeds drop their seeds on the soil surface, and some species will not germinate when plowed under. But some weed seeds may survive for many years in the soil. Any technology that is employed to eliminate sources of pest infestation will reduce the chances of pest outbreaks.

Destroying weeds and other vegetation close to crops to achieve a clean culture, however, may not always be beneficial. The grape leafhopper and its parasite are normally maintained at low levels on the blackberry growing in vineyard borders. When the leafhopper invades the grapes, the readily available parasites on the blackberry invade the vineyard at the same time and provide control of the leafhopper. As a result, leaving wild blackberry to grow adjacent to grape vineyards has helped to maintain a parasite population that has provided the prime means of control of the grape leafhopper.

Combination Plantings

Planting appropriate combinations of crops together may help to reduce the pressure of major peats on each crop [5]. For example, in central America, combinations of maize and beans grown together have had fewer pest problems than either crop grown by itself. So far, this technology has not been used extensively in other locations, but it deserves greater attention.

Although the combination planting of certain crops has advantages, it may also result in more serious post outbreaks than if each crop were grown as a monoculture. For example, growing maize in association with either cotton or tobacco is more likely to increase some pest-insect populations than if the crops were produced as monocultures. The ecology of each crop must be clearly understood before combinations are used.

Barriers

To a limited extent, cardboard, plastic, and other types of physical barriers have been used to control insects and weeds. Thus, wrapping the stems of trees and shrubs with paper tape may prevent insect borers from attacking them.

The most widespread and successful use of barriers has been in weed control, where organic and black plastic mulches have proved to be highly effective. However, this technique is costly in both labor and materials and is generally used with high-value crops such as market-garden vegetables.

Although organic mulches are effective in controlling weeds, they may encourage other pests such as slugs and mice. Heavy organic mulches may also reduce soil temperatures and thus reduce germination and rate of growth of certain crops; plastic mulches can increase water runoff from the crop fields and cause flooding of other land.

Disease-free Propagation

Destruction of valuable crops by plant pathogens can be prevented by planting only disease-free propagated material and thereby eliminating the source of any plant pathogens. In the United States this practice is widespread, especially in fruit trees. Now, nearly all fruit trees are certified disease-free nursery stock.

Fortunately, no known risks are associated with this nonchemical control technology when practiced as described above.

INTEGRATED PEST MANAGEMENT AND THE FUTURE

For the farmer, the main advantage of IPM is reducing the amount of pesticide, that in used. This reduces the cost of pest control while protecting the environment and public health.

A weakness of IPM in the need for research to establish the technologies, which are more complex and sophisticated than routine spraying. In addition, educating farmers in the use of IPM technologies is more difficult than training then to spray crops once a week or once in two weeks.

What are the immediate prospects for IPM in developing countries?

They are good in those situations where farmers can be educated to monitor the pests in their crops and "treat only when necessary." Local agricultural research and extension officials and farmers often have a sense of the "economic-injury level" and can thus develop an initial IPM program for "treating when necessary."

For the long term, devising pest-control strategies with the necessary degree of sophistication will require the joint efforts of such specialists as entomologists, plant pathologists, weed specialists, agronomists, plant breeders, and horticulturalists.

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